

# Post-Knox Unconformity—Significance at Unionport Gas-Storage Project and Relationship to Petroleum Exploration in Indiana

By STANLEY J. KELLER *and* TALAL F. ABDULKAREEM

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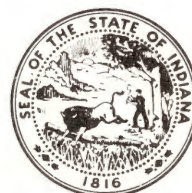
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PRINTED BY AUTHORITY OF THE STATE OF INDIANA  
BLOOMINGTON, INDIANA: 1980

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# Post-Knox Unconformity—Significance at Unionport Gas-Storage Project and Relationship to Petroleum Exploration in Indiana

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## Abstract

The post-Knox unconformity provides the principal trapping conditions for underground gas storage at Unionport in Randolph County. Erosion remnants of the porous Knox Dolomite protrude upward into the overlying impermeable Black River Limestone.

Although the unconformity has long been recognized in Indiana, data for detailed mapping of its surface are lacking except at Unionport. Here about 50 wells drilled to the Knox outline a surface of steep-sided, ovate erosion remnants of limited lateral extent with vertical relief of about 150 feet. No drainage pattern is evident. The unconformity is postulated to have been developed in an arid environment with wind as the primary erosion agent.

The erosion-induced irregularity of the post-Knox unconformity is only slightly reflected on the top of the Trenton Limestone. The composite thickness from the top of the Trenton to the top of the Knox ranges from 400 to 530 feet at the Unionport gas-storage project.

Petroleum has been produced in Indiana, Ohio, Kentucky, and southern Ontario from erosion remnants associated with the post-Knox unconformity. We feel that petroleum deposits under similar geologic conditions exist in Indiana and that the crestal area of the Cincinnati Arch provides the most favorable general area for exploration.

## Introduction

Throughout Indiana and adjoining states the Ordovician System contains a major unconformity between the Knox Dolomite and the overlying rock units. This unconformity exists in the subsurface rocks of Indiana at depths ranging from 1,500 to 7,500 feet. Beneath the unconformity, natural gas is stored at Unionport and Sellersburg and oil has been produced at Redkey. Therefore the uncon-

formity has been demonstrated to have had a direct relationship to hydrocarbon entrapment.

The Unionport gas-storage project (Randolph County), the Sellersburg gas-storage project (Clark County), and the Redkey pool in the Trenton Field (Jay County) (fig. 1) are three separate areas in Indiana in which the post-Knox unconformity influences the trapping conditions. Only at Unionport is it possible to do any detailed mapping on the unconformity. At the Unionport gas-storage project about 50 wells have been drilled to the Knox. From this concentration of well data we attempted to reconstruct the geologic conditions associated with the unconformity as related to gas storage. We felt that these conditions would reflect similar entrapments likely existing in other parts of Indiana.

The Unionport area of Randolph County lies in east-central Indiana near the Ohio state line. This area of study includes about 45 square miles surrounding the gas-storage project (fig. 1).

## Purpose and Method of Study

This report presents the subsurface geology of rock units ranging from the Knox Dolomite through the Trenton Limestone (fig. 2) in the area of the Unionport gas-storage project. Particular emphasis is placed on determining the relationship between the unconformity and its effect on entrapment conditions for underground gas storage.

Structure maps were compiled on the top of the Knox Dolomite and the top of the Trenton Limestone, and thickness maps of the Glenwood Shale, the Black River Limestone, and the Trenton Limestone were also compiled (fig. 2). Detailed structure cross sections were constructed to show the subsurface structure and stratigraphic sequence of the rock units.



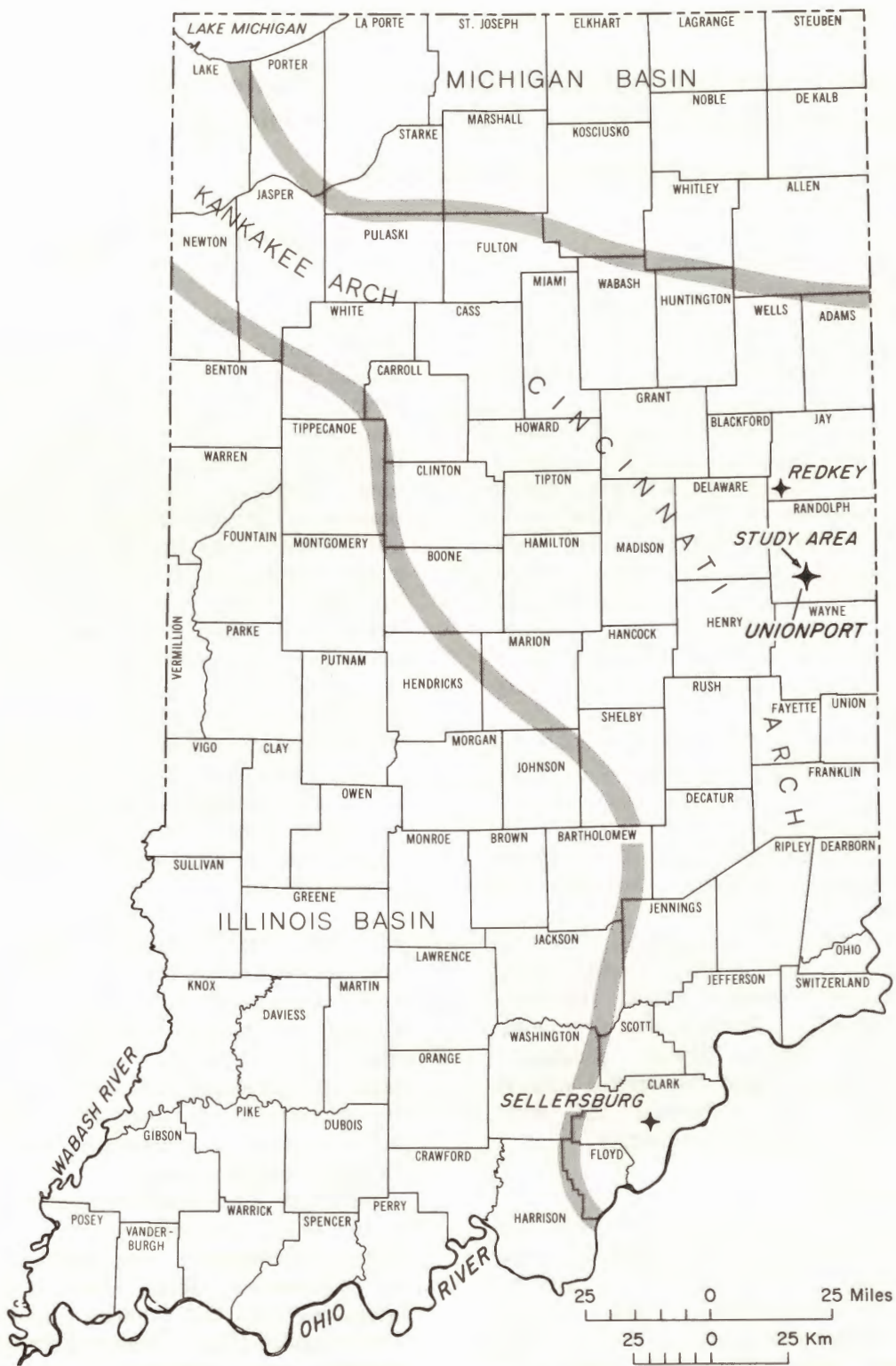


Figure 1. Map of Indiana showing counties, geologic provinces, and study area in Randolph County. Sellersburg, Unionport, and Redkey are features associated with the post-Knox unconformity. Modified from Carpenter, Dawson, and Keller, 1975, fig. 8.


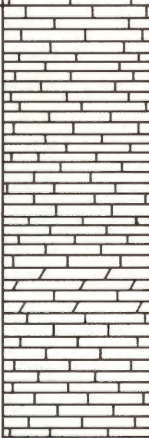
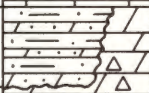
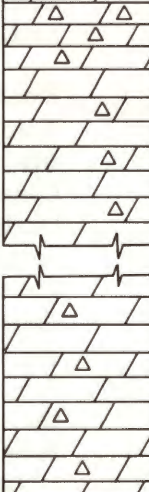
SYSTEM	SERIES	FORMATION		THICK- NESS (FT)	LITHOLOGY
ORDOVICIAN	CHAMPLAINIAN	Trenton Limestone		100 to 130	Limestone, tan, very finely to medium crystalline, dolomitic in upper part
		Black River Limestone		270 to 350	Limestone, tan to gray, micro-crystalline; some dolomitic limestone; trace of thin greenish bentonite (B)
		Glenwood Shale		0 to 60	Shale, greenish, and dolomite, tan, finely crystalline; quartz sand grains
CAMBRIAN	ST. CROIXAN	Knox Dolomite		1000	Dolomite, tan, very finely to medium crystalline; abundant white chert; trace of pyrite and dark shale

Figure 2. Generalized stratigraphic section for the Unionport area.

Data for this report have been gathered from nearly 90 well records on file in the Petroleum Section, Indiana Geological Survey, Bloomington, Ind. Well data used included laterlog-gamma ray-neutron logs,

drillers logs, sample logs, scout tickets, and colored strip logs. Gas-storage capacities and some reservoir characteristics were provided by the owner of the field, Indiana Gas Co., Inc., Indianapolis, Ind.



## Acknowledgments

We express our appreciation to Dr. John B. Patton, State Geologist, who suggested this study. His advice and encouragement proved helpful. Special thanks are extended to Mr. G. L. Carpenter and to other members of the Petroleum Section, Indiana Geological Survey, for their assistance.

## Regional Geology

Sedimentary rocks in Indiana range from Late Cambrian to Late Pennsylvanian in age. Within the study area the sedimentary rocks range from Late Cambrian to Middle Silurian in age, but only Ordovician rocks were examined in detail for this report.

The most prominent and widespread positive structural feature in Indiana is the Cincinnati Arch, which extends from southeastern to northwestern Indiana, where it merges into the Kankakee Arch. Flanking the arch on the north is the Michigan Basin and on the southwest is the Illinois Basin (fig. 1). The Cincinnati Arch was not present during Ordovician time as evidenced by the Maquoketa Group (Upper Ordovician), which thins from nearly 1,000 feet in eastern Indiana to 200 feet in western Indiana (Gray, 1972, p. 1). Reports by Gutstadt (1958) and Becker, Hreha, and Dawson (1978) included isopach maps of various rock units older than the Maquoketa that show these older rock units thinning and thickening in so many different directions that the Cincinnati Arch could not have been present at that time. The overlying Silurian rocks reflect the first influence of the uplift associated with the formation of the Cincinnati Arch during middle to late Paleozoic time.

The Ordovician rocks in the study area are primarily limestones and dolomites of Early and Middle Ordovician age and shales of Late Ordovician age. Only the limestone and dolomite sections are discussed in this report. The stratigraphic units associated with the Unionport area and considered in this report are the Knox Dolomite, the Glenwood Shale, the Black River Limestone, and the Trenton Limestone (fig. 2). In western Indiana, rocks found at the same stratigraphic position as the Glenwood include the Joachim Dolomite and the St. Peter Sandstone. All three formations

were referred to by Gutstadt (1958, p. 52) as belonging to the Chazy Series and have been referred to by many as merely Chazy. But the terms Chazy and Chazy Series are no longer in formal use by the Indiana Geological Survey.

Throughout Indiana the top of the Knox Dolomite is an unconformity. The unconformity is overlain by so-called "Chazy" rocks nearly everywhere except where the relief on the unconformity is great enough that Black River rocks rest directly on the Knox. On the basis of the amount of data available for study, these topographically high relief areas (or simply "Knox highs") are totally unpredictable in their occurrence. We assume that because of the extensive geographic distribution of the unconformity, Knox highs would be numerous, restricted in size (40 acres or less), circular to ovate, and randomly distributed in the subsurface. Recognition of the unconformity can best be made from drill cuttings or cores, although geophysical logs, despite having limited distinctive inflections, could be used if proper caution is exercised.

## Post-Knox Unconformity

Throughout much of North America there was an interruption in deposition during late Canadian and early Champlainian time. During that time the Canadian sediments were subareally exposed and subject to erosion. In Indiana this contact cannot be observed, as Canadian rocks do not crop out in the state. But Gutstadt (1958, p. 52) referred to the "unconformity at the top of the Canadian" in the subsurface, and we refer to this unconformity as the post-Knox unconformity.

The post-Knox unconformity in Indiana, an erosion surface, was postulated by Patton and Dawson (1969, p. 34) as having developed in an arid environment, characterized by a widespread rocky desert at the beginning of Middle Ordovician time. Dawson (1967, p. 130 and fig. 3) also said "erosion of the Knox Dolomite appears to have been caused by deflation (removal of fine-grained surface material by wind)" and "erosional remnants stand abrupt and high—the remnants, butte-like in form, are of the type developed in arid climates." Evidence for an



abundant supply of sand for windblown erosion of the arid post-Knox erosion surface is found in southeastern Indiana, where Knox sand attains a thickness of more than 300 feet in Jennings County and thins eastward toward Ohio (Patton and Dawson, 1969, figs. 6 and 7). Sand-filled fractures in the top of the Knox Dolomite have been observed by James O. Wood at the Sellersburg gas-storage project in Clark County (oral communication, 1980). Some other factors favoring an arid environment include steep-sided erosion remnants of carbonate rock, an apparent absence of solution cavities or features, no apparent drainage patterns, and rounded sand grains in the overlying Glenwood.

The Glenwood marks the resumption of deposition after the unconformity. In addition to the scattered sand grains mentioned above, the Glenwood rocks on top of the unconformity are fine-grained dolomite and green shale. The dolomite and shale are highly interbedded so as to suggest a gradual encroachment of the sea during Glenwood deposition. This period of transition from an arid to a marine environment may have been fairly short lived, as the rock record is thin—less than 60 feet. After Glenwood deposition, the seas completely covered the area, and fine carbonate mud was deposited. This mud became the dark microcrystalline Black River Limestone, which completely blanketed the area and forever buried the post-Knox unconformity.

### The Trenton Field and the Cincinnati Arch

Most of Randolph County is within the almost totally abandoned Trenton Field of east-central Indiana (fig. 3). The Trenton Field produced more than 105 million barrels of oil and a trillion cubic feet of natural gas. Most of this production was during the peak years from 1886 to 1910 (Carpenter, Dawson, and Keller, 1975, p. 25 and 30). All production was from Ordovician rocks. The Trenton Limestone yielded most of the oil and all of the gas; the Black River Limestone yielded some oil, and the upper part of the Knox yielded a small amount of oil.

Although the uplift which formed the Cincinnati Arch postdates the Ordovician, the

arch is generally considered an influencing structural condition for petroleum accumulation in the Trenton Field. This same structural influence could be postulated as a factor for petroleum accumulation in the Knox Dolomite. Therefore, Knox erosion remnants along the crestal portion of the arch would seemingly be more favorable for petroleum entrapment than remnants along the flanks of the arch.

### Formations and Their Lithologies at Unionport

The studied rock units range in age from Late Cambrian (lower part of the Knox Dolomite) to Middle Ordovician (Glenwood Shale, Black River Limestone, and Trenton Limestone) (fig. 2). The Glenwood is absent in western Indiana, where correlative rock units are the St. Peter Sandstone and the Joachim Dolomite. These three formations have been referred to as the Chazy (Gutstadt, 1958). The rock units from oldest to youngest considered in this study are Knox, Glenwood, Black River, and Trenton.

#### KNOX DOLOMITE

The Knox is white to tan very finely to medium crystalline dolomite; it has uniform texture and appearance throughout its entire 1,000 feet of thickness. White chert, partly oolitic, occurs in all of the Knox, but the largest concentration of chert is found in the upper 200 feet of the formation. Traces of pyrite and thin dark shales are rare. The porosity of the Knox is about 6 to 8 percent at Unionport.

In Randolph County the Knox is conformably underlain by the Davis Formation (Becker, Hreha, and Dawson, 1978) and unconformably overlain by Glenwood rocks.

#### GLENWOOD SHALE

The Glenwood rocks are composed of alternating strata of greenish shale and tan finely crystalline dolomite with disseminated rounded and frosted medium-size sand grains. Glenwood rocks have a rather dull-to-earthly texture in part. The unit contains some thin dark petroliferous-appearing streaks. Traces of pyrite are rare; chert is absent. Thickness ranges from 0 to 60 feet. Porosity is spotty



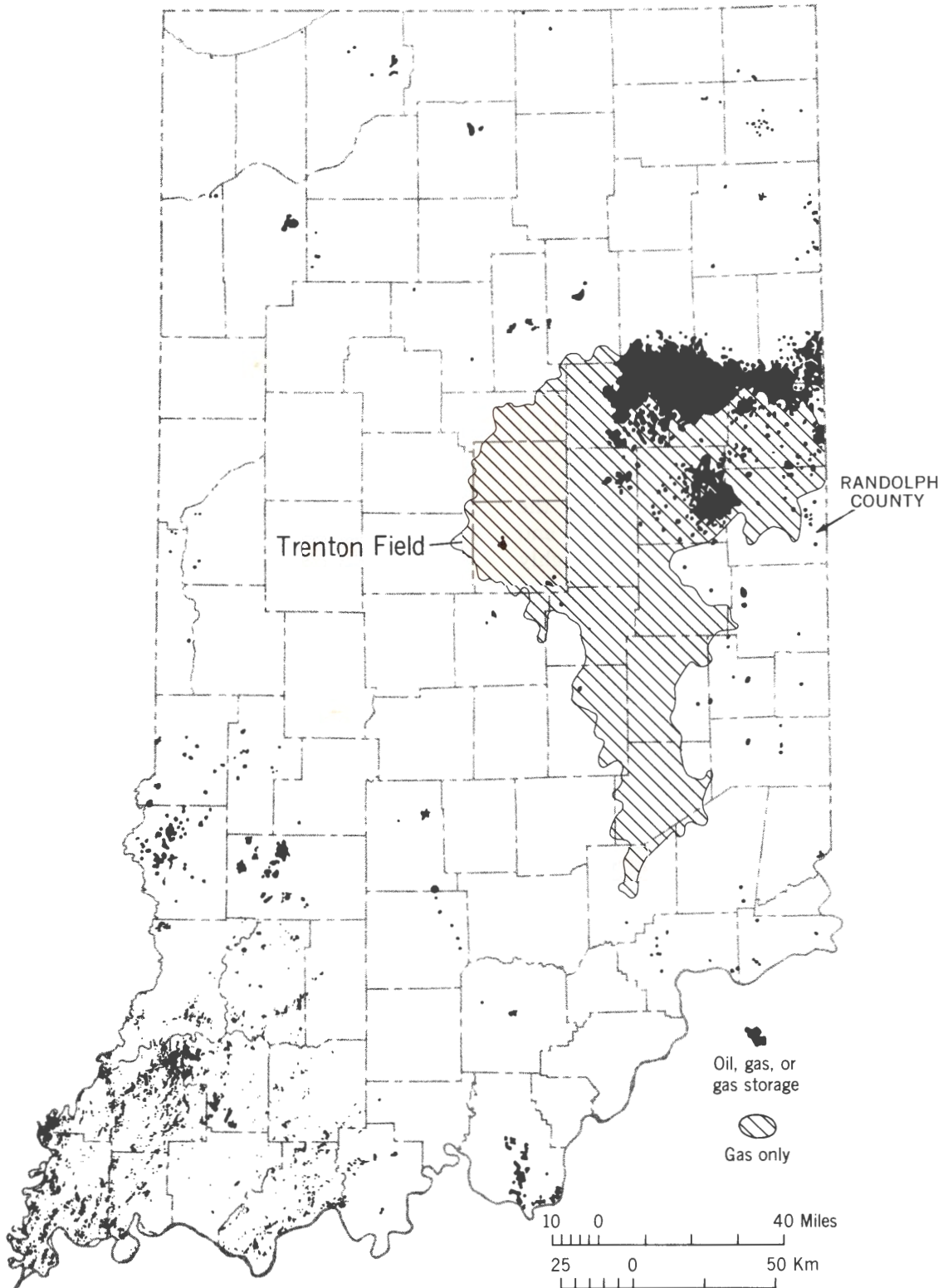


Figure 3. Map showing location of oil and gas fields in Indiana. Modified from Carpenter, Dawson, and Keller, 1975, fig. 9.

and reaches a maximum 16 percent. The Glenwood is overlain conformably by the Black River Limestone except where erosion has removed the Glenwood and the Black River rests unconformably on the Knox.

#### BLACK RIVER LIMESTONE

Black River rocks are predominantly tan to gray microcrystalline limestone, but some dolomitic rocks range from 5 to 10 feet in thickness in the lower half of the formation. The texture is lithographic except in the dolomitic sections, where it is finely crystalline. Distinctive greenish-gray very thin bentonite beds occur at the top of the formation and again about 50 feet below the top. Both bentonite beds have a distinctive kick on the radioactivity log; the gamma-ray curve deflects to the right and the neutron curve to the left. The Black River ranges from 270 to 350 feet in thickness at Unionport. It is thinnest over Knox erosion remnants. Porosity is low except in the thin dolomitic zones, where it reaches a maximum 9 percent. The Black River is overlain conformably by the Trenton Limestone.

#### TRENTON LIMESTONE

Trenton rocks are tan very finely to medium crystalline limestone with some interbedded dolomitic limestone strata that include lenses of vuggy dolomite. The upper 20 feet of the Trenton is brown, which is partly due to petroliferous staining. The texture is mostly uniformly crystalline. No pyrite or chert is evident. Thickness ranges from 100 to 130 feet, and porosity averages about 3 percent and reaches a maximum 12 percent. The Trenton is overlain conformably by the Maquoketa Group (Late Ordovician in age).

### Regional Structure in Randolph County

The Trenton Limestone provides the only surface on which sufficient subsurface data exist for compiling a structure map in Randolph County (fig. 4). The Trenton surface is structurally highest in the southwestern part of the county, where it is nearest the crest of the Cincinnati Arch in Indiana. The regional dip increases northeasterly from 5.5 feet per mile to 11 feet per mile. The

strike of the Trenton surface forms an arcuate pattern from southeast to northwest paralleling the crest of the Cincinnati Arch. Local structurally high anomalies occur in the western part of the county. The most prominent of these is a northeasterly gently plunging nose in the study area (fig. 4)—the Unionport area. Although subsurface well control on the Knox Dolomite is insufficient throughout the county for establishing detailed knowledge of the thickness of rocks between the Trenton and the Knox, large variations appear to be limited to areas of known Knox erosion remnants that abruptly shorten the thickness. By ignoring these short intervals the configurations of the Knox and Trenton surfaces are interpreted to have similar strikes and dips.

### Effect of Post-Knox Unconformity at Unionport

The post-Knox unconformity at Unionport is an undulating surface featuring abrupt steep-sided erosion remnants of limited areal extent (fig. 5A, B, C). Relief on the Knox surface reaches as much as 135 feet in a lateral distance of about 600 feet. The rocks lying directly on the unconformity are either the Glenwood or the Black River. Both formations thin toward the crests of erosion remnants, and the Glenwood is totally absent from areas of maximum relief. The thinning effect of the remnants appears to have had only slight influence on the Trenton thickness. The Knox highs are reflected in both the Black River and the Trenton.

The unconformity and the top of the Knox Dolomite are the same surface. Topographic relief on top of the Knox at Unionport reaches a maximum of 160 feet (fig. 6). Local closures on the Knox surface suggest a series of isolated highs with a northeast-southwest orientation, but this interpretation might change if the density of well control were uniform throughout the area. Increased drilling might reveal many other Knox erosion remnants and possibly a different orientation.

Where the erosion remnants are of sufficient relief, Glenwood rocks are absent (fig. 7). Their absence is likely due to nondeposition, as the Glenwood shows marked thinning onto the Knox highs.



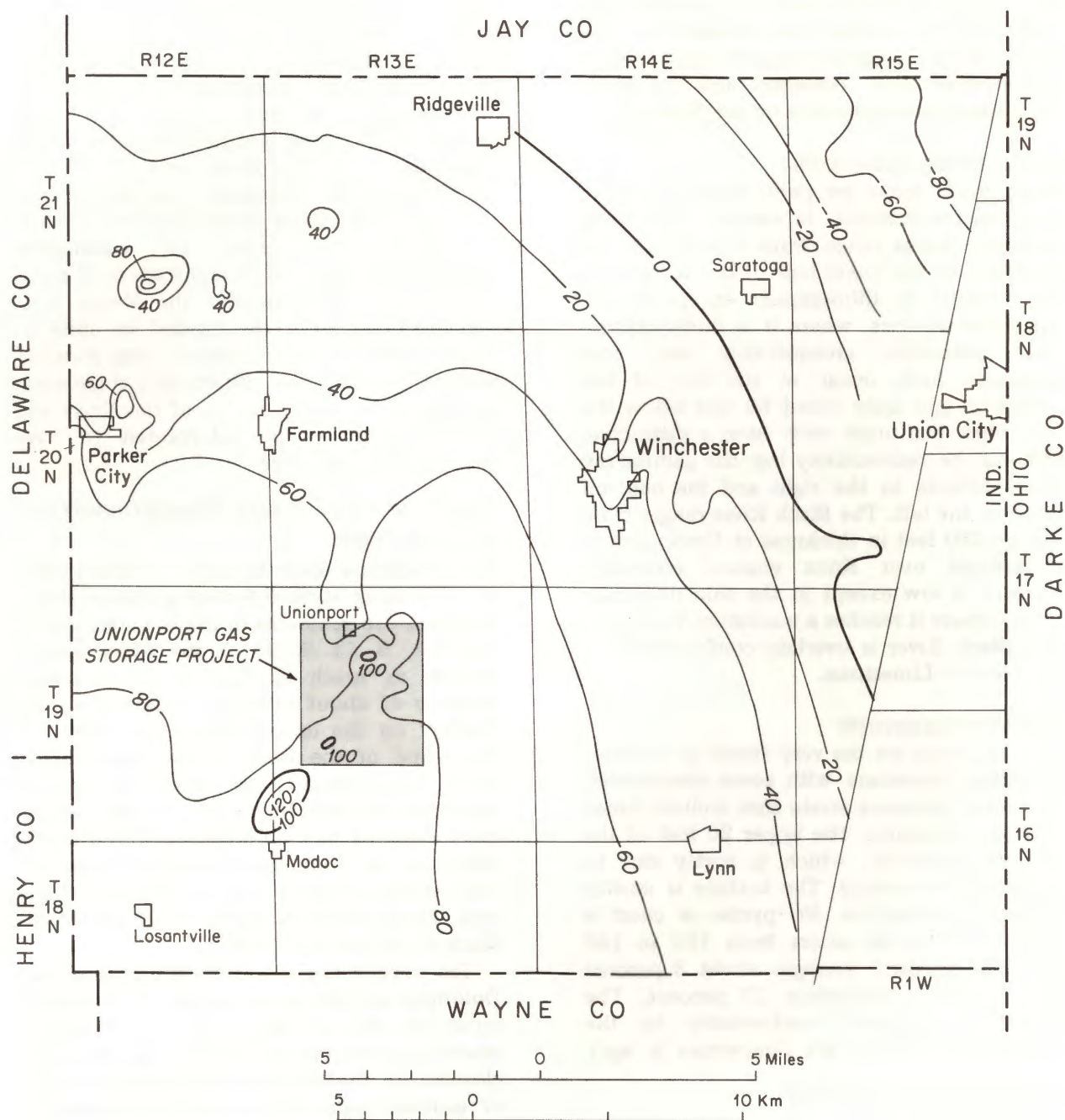


Figure 4. Map of Randolph County showing structure on top of the Trenton Limestone. The Unionport study area is outlined. Contour interval is 20 feet. Datum is mean sea level.

Thickness ranges from 0 to 60 feet (fig. 7). Besides, the drill cuttings from the wells do not provide any tangible evidence that the Glenwood sediments were reworked. Where Glenwood sediments are absent, the porous

Knox erosion remnants are encased in the impermeable microcrystalline rocks of the Black River Limestone. This provides an effective trap for hydrocarbons.

# EFFECT OF POST-KNOX UNCONFORMITY AT UNIONPORT

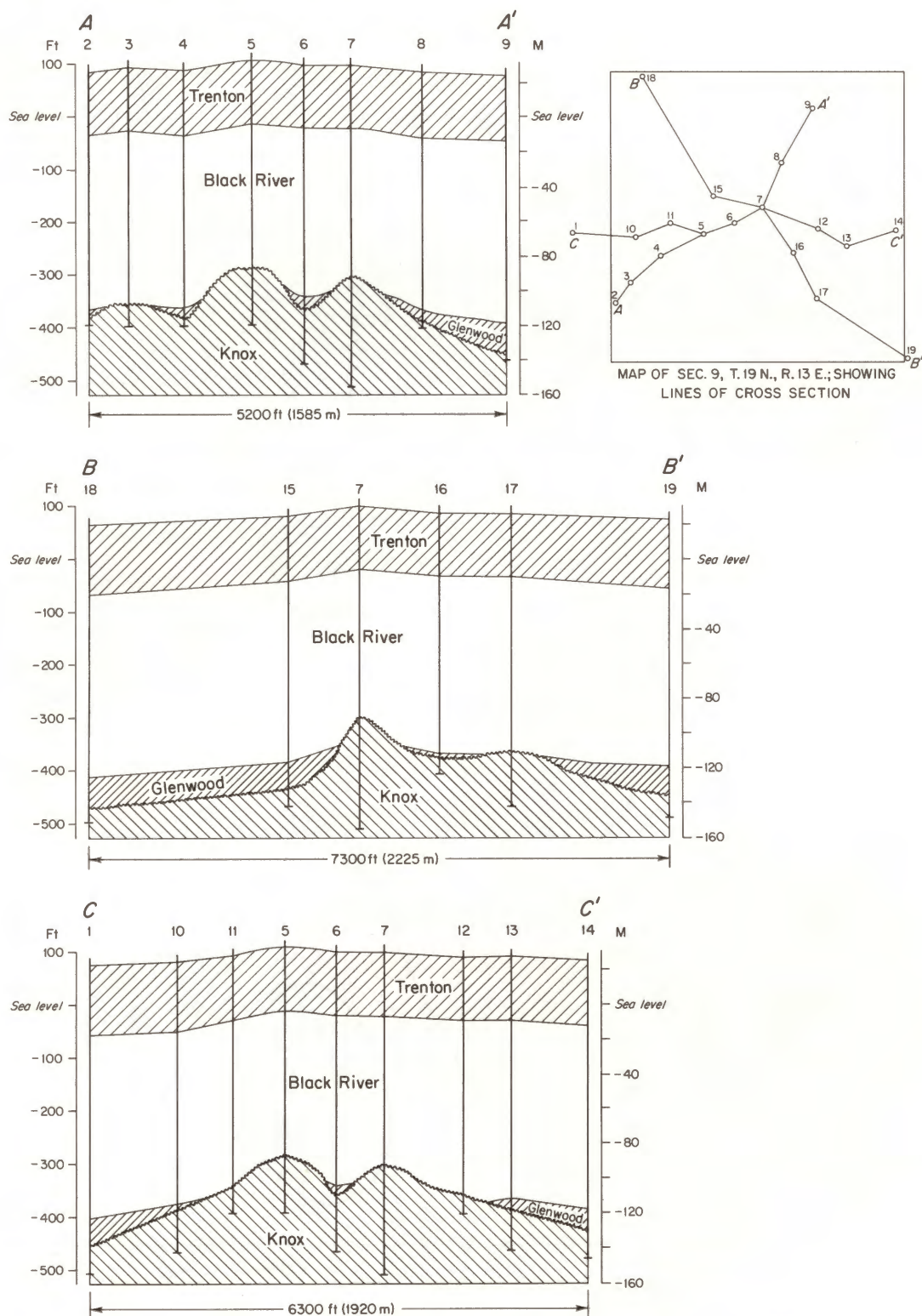


Figure 5. Structure cross sections A, B, and C showing the post-Knox unconformity in the Unionport gas-storage project. See appendix for wells used in cross sections. Vertical exaggeration is 6.6X.



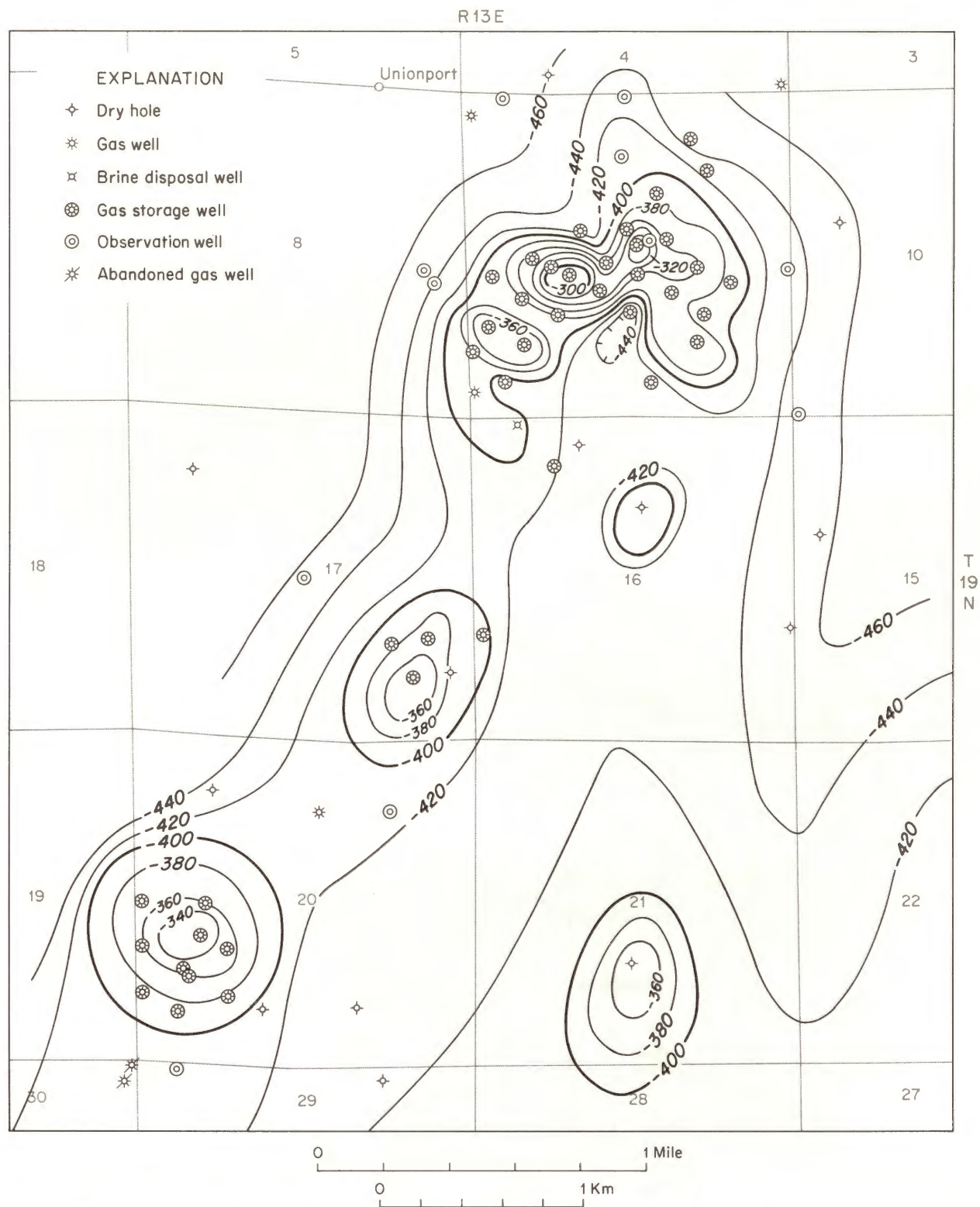


Figure 6. Map showing structure on top of the Knox Dolomite in the Unionport gas-storage project. Contour interval is 20 feet. Datum is mean sea level.

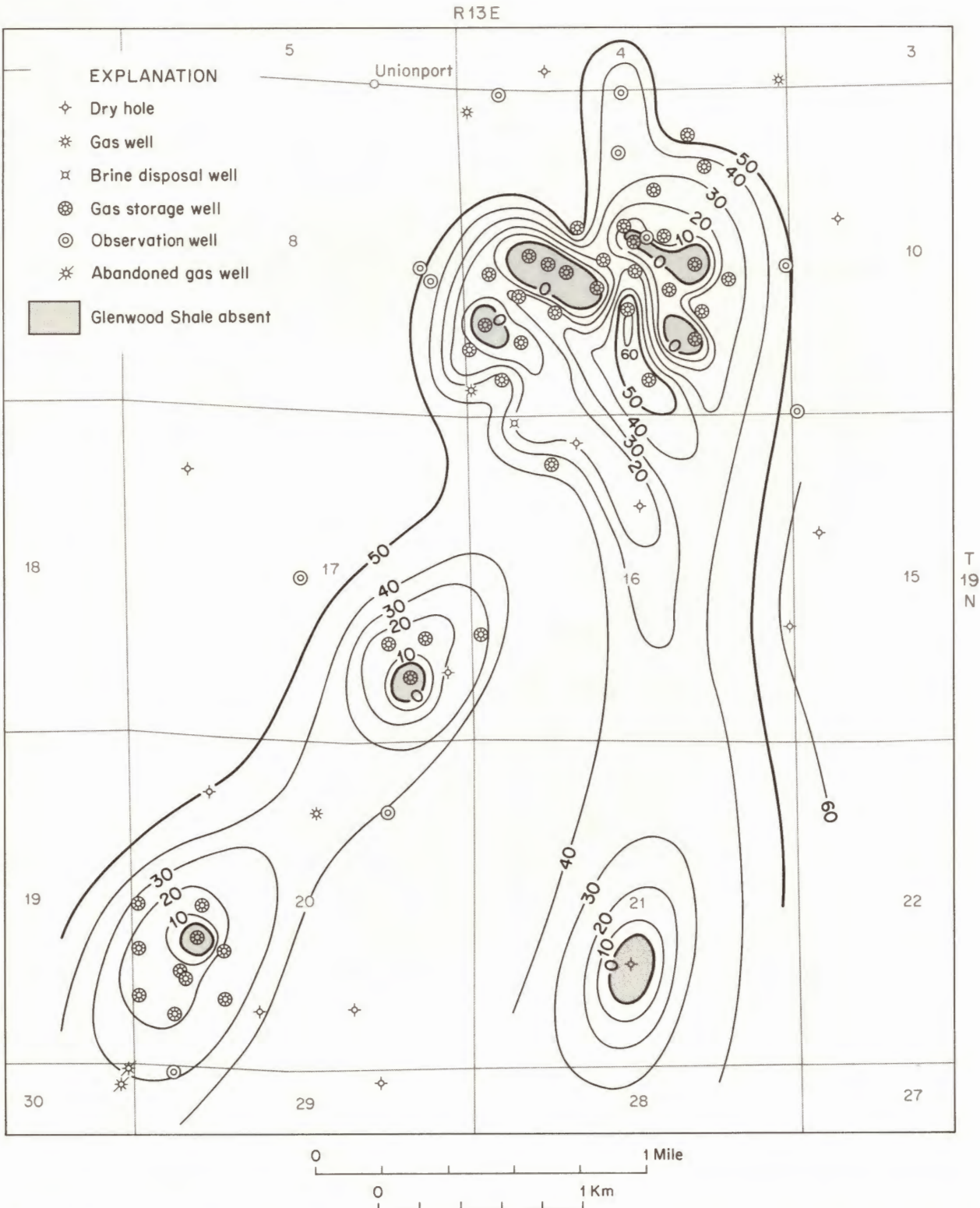


Figure 7. Map showing thickness of the Glenwood Shale in the Unionport gas-storage project. Contour interval is 10 feet.



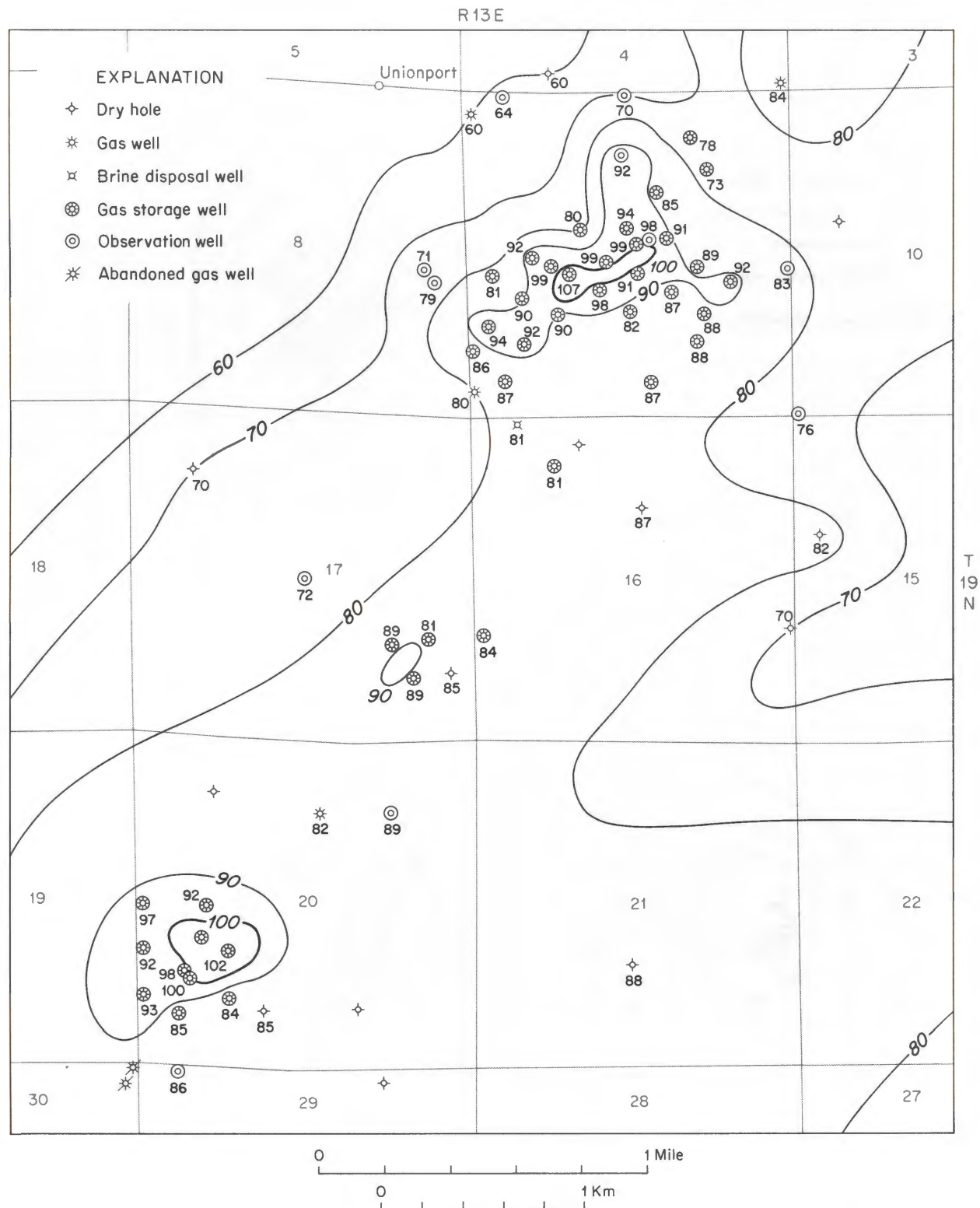


Figure 8. Map showing structure on top of the Trenton Limestone in the Unionport gas-storage project. Numbers beside well symbols indicate the elevation (in feet) of the top of the Trenton Limestone. Contour interval is 10 feet. Datum is mean sea level.

The slopes on top of the Trenton Limestone resemble those on the Knox surface but are more subdued (fig. 8). The strike and dip of the northeastward-plunging anticlinal nose in both formations are essentially the same, but the relief on the Trenton is less than that on the Knox. Closure on the Trenton at Unionport is only about 20 feet as opposed to more than 100 feet of closure on the Knox. The lesser amount of closure on the Trenton surface results from the masking effect of Black River rocks having been differentially deposited and differentially compacted over Knox erosion remnants. We postulate that most Knox highs are reflected to some degree on the Trenton surface, but that all Trenton highs do not necessarily reflect a Knox high, as the Trenton surface is known to be undulating in parts of Indiana. Rooney (1966) said that the contact between the Maquoketa Group and the underlying Trenton Limestone is a disconformity, but no evidence of a disconformity exists at Unionport.

Thickness variations at Unionport are apparent in the Black River and Glenwood rocks (fig. 5A, B, C and fig. 7). The composite thickness from the top of the Trenton to the top of the Knox presents an accurate assessment of the total range in variations for the entire rock section under study. The composite thickness ranges from 400 to 530 feet (fig. 9). The thinner sections correlate with the Knox highs, but the thicker sections represent areas of little relief on the post-Knox unconformity.

### Natural-Gas Storage at Unionport

Underground storage of natural gas at Unionport was initiated in 1960 by Central Indiana Gas Co. To date (1980) 42 gas-storage wells have been completed. The particular area was selected for storage because it contained a small group of isolated Trenton gas wells. The total gas-storage area covers about 670 acres. Indiana Gas Co., Inc., is the present operator of the project, which is divided into two parts—the Unionport project and the Unionport South project (fig. 10). The company commonly refers to them as the “North field” and the “South field.”

In the North field gas is stored in the Knox and Glenwood rocks at a depth of about 1,500 feet. The North field has a total capacity of 1.1 billion cubic feet and a working capacity of 440 million cubic feet. In the South field gas is stored primarily in the Trenton Limestone at a depth of about 1,000 feet. The South field has a total capacity of 355 million cubic feet and a working capacity of 68 million cubic feet. Total storage capacity of both projects at Unionport is 1.455 billion cubic feet, and total working capacity is 508 million cubic feet.

According to the company, the Knox reservoir has a permeability of 25 to 50 millidarcies and porosity of 6 percent. Permeability and porosity in the Glenwood reservoir have not been reported but are probably similar to those of the Knox. Dawson and Carpenter (1963, table 2) listed the average porosity at 6 percent and average permeability at 1 millidarcy for the Trenton reservoir.

The trapping conditions in the deeper Glenwood-Knox reservoir result from erosion remnants developed along the post-Knox unconformity that are enclosed by the overlying impermeable Black River Limestone. Although closure is much less, these same conditions may cause entrapment in the shallower Trenton reservoir, with the overlying impermeable Maquoketa shales acting as the seal. Varying permeability may have contributed to entrapment in the Trenton, as this factor influences other Trenton gas fields in adjacent areas.

The geologic conditions that determine the capacity of a gas-storage field include structural closure, thickness of the reservoir rocks, effective porosity, the conditions of fluid flow through the rock (permeability), the pressure at which the fluids and gases exist in the reservoir, and the areal extent of the reservoir.

### Unconformities and Petroleum Entrapment

Unconformities have historically provided good conditions for petroleum entrapment—both stratigraphically and structurally. Many of the world's oil and gas fields are associated



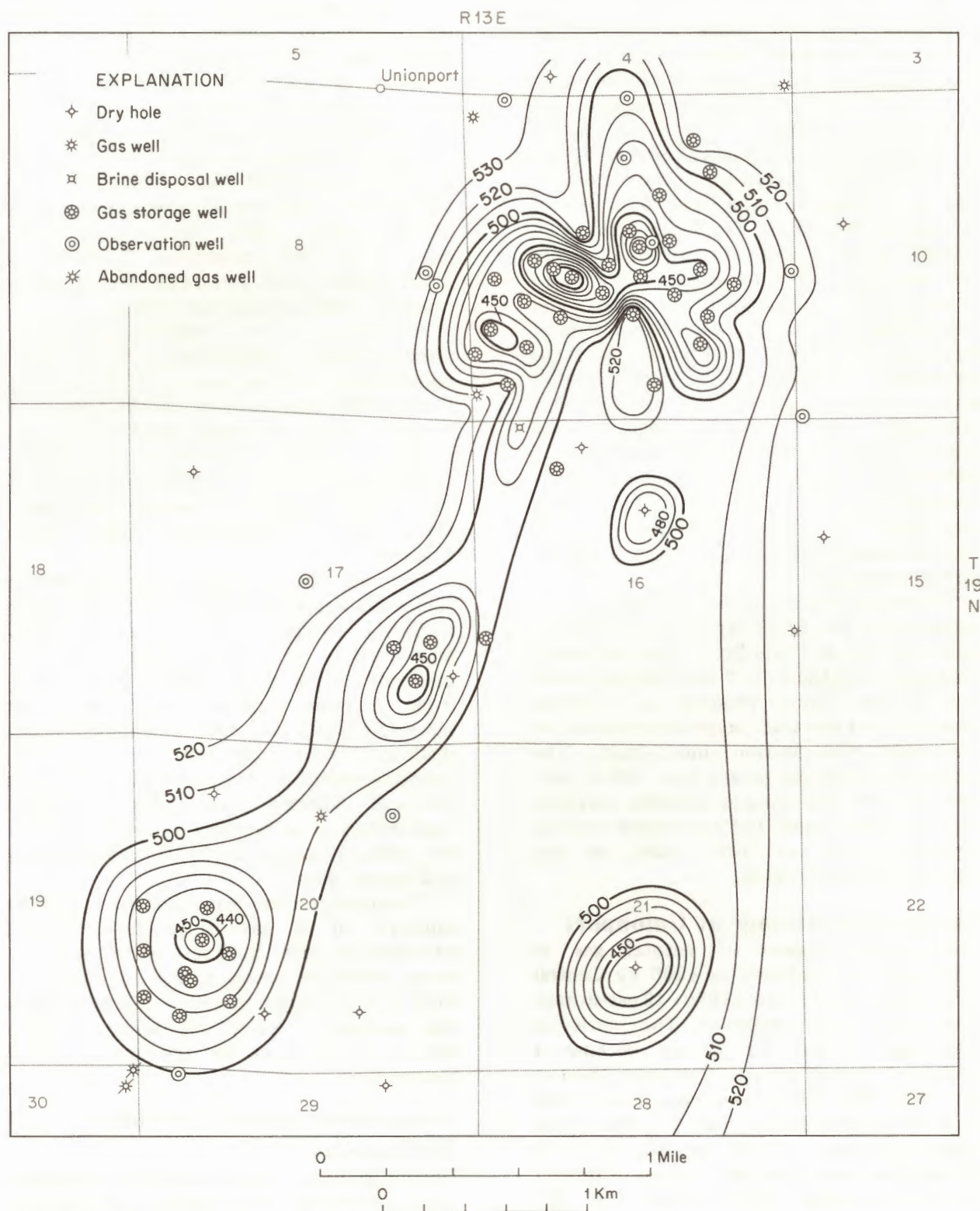


Figure 9. Map showing composite thickness of Trenton, Black River, and Glenwood rocks in the Unionport gas-storage project. Contour interval is 10 feet.

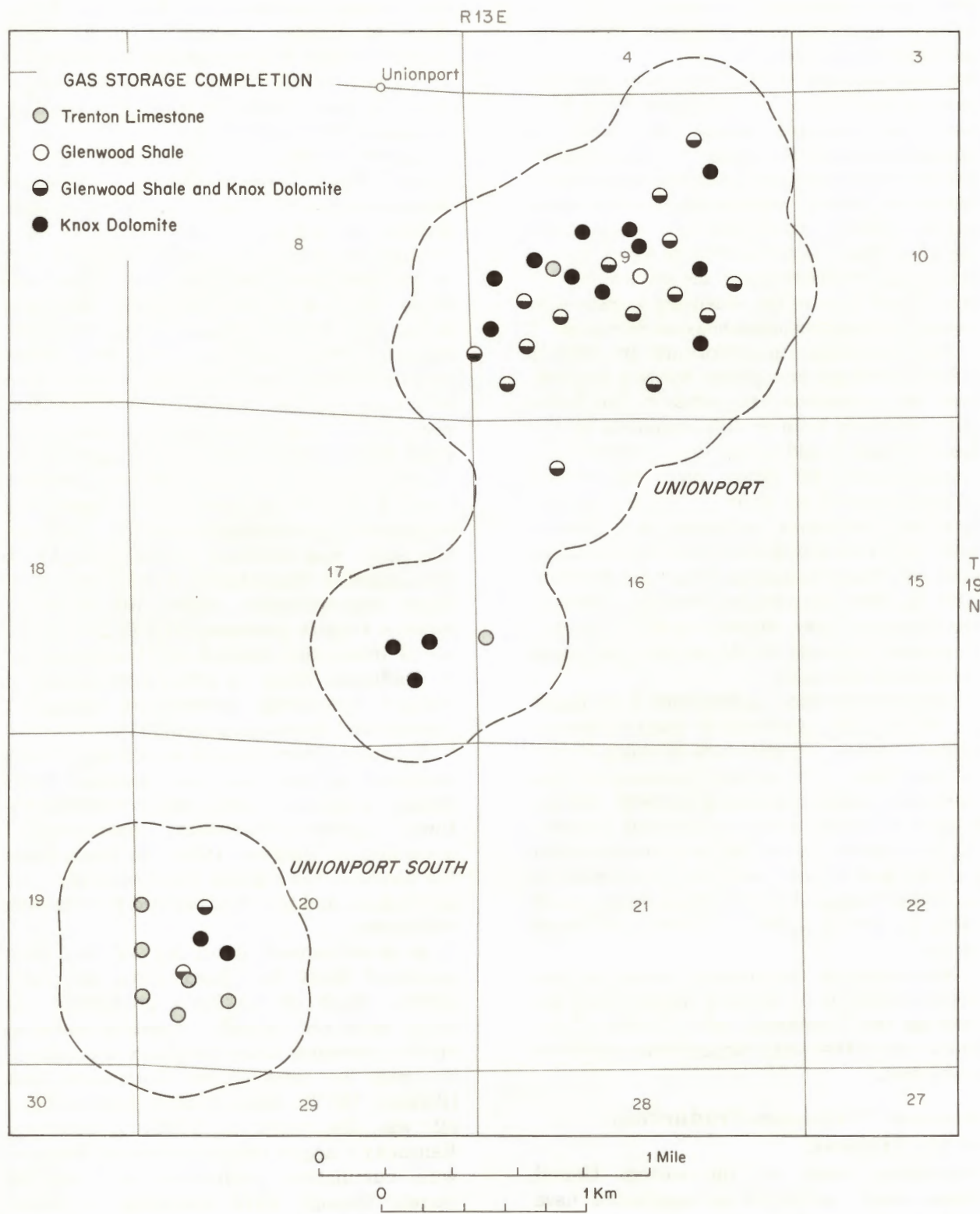


Figure 10. Map showing location of gas-storage wells in the Unionport gas-storage project.



## Summary

The Unionport area presents a concise case history demonstrating the effect of the post-Knox unconformity on the overlying rock strata. The high relief generated by Knox erosion remnants provides an ideal trap in which to store natural gas. The top of the Trenton Limestone displays limited closure above the Knox erosion remnants. Adequate porosity and permeability exist in the Trenton and the Knox to contain hydrocarbons. Many similar Knox highs are believed to exist in Indiana, and some of them can reasonably be expected to contain oil or gas.

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## Appendix: Wells in Randolph County Used in Cross Sections

No.	Location			Operator and well name
	Sec.	T.	R.	
1	8	19 N	13 E	Central No. 8-C Clark
2	9	19 N	13 E	Central No. 9T35 Clark
3	9	19 N	13 E	Central No. 9T22 Clark
4	9	19 N	13 E	Central No. 9T29 Arnold
5	9	19 N	13 E	Central No. 9T18 Cullison
6	9	19 N	13 E	Central No. 9T10 Cullison
7	9	19 N	13 E	Central No. 9T56 Johnson & Jarrett
8	9	19 N	13 E	Central No. 9T34 Johnson
9	9	19 N	13 E	Central No. 9T40 Johnson
10	9	19 N	13 E	Central No. 9T31 Cullison
11	9	19 N	13 E	Central No. 9T19 Cullison
12	9	19 N	13 E	Central No. 9T23 Watson
13	9	19 N	13 E	Central No. 9T39 Watson
14	9	19 N	13 E	Central No. 9T14 Watson
15	9	19 N	13 E	Central No. 9T20 Cullison
16	9	19 N	13 E	Central No. 9T25 Arnold
17	9	19 N	13 E	Central No. 9T38 Watson
18	9	19 N	13 E	Central No. 9-M Cullison
19	10	19 N	13 E	Central No. 10T15 Wasson

